Simulation Studies for Recoil Detectors

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The purpose of the calibration experiment is to transfer the known polarization of a jet target to the analyzing power of the CNI polarimeters by first obtaining the beam polarization from the observation of p+p elastic scattering from the RHIC beam passing through the polarized jet. Elastic scattering is a preferred process since it offers the same analyzing power for both beam and target. The p+p CNI region offers large cross sections and analyzing powers that are reliably on the scale of a at least a few percent over a range of energies.

If p+p recoils are observed on both sides of the beam and it is possible to flip the spins of either the target or the beam, then there are 8 available experimental quantities. If normalized to a luminosity monitor (an issue that must deal with spin correlations), certain combinations (see slide 2) of these 8 rates yield quantities proportional to just the beam or target polarization. The ratio of these two is the first step in the calibration. Other combinations yield information independently on "reversal failures" in which either the target or beam polarization does not complete reverse, or there are asymmetries between the left and right detector efficiencies.

The count rate estimates on slide 3 suggests that we can obtain the 1.3M events needed for a 5% calibration in roughly one day of continuous running.

The atomic beam target, which will be about 1.2 cm across, will sit in a holding field that must be at least 1 kG to avoid depolarizing resonances from RF in the beam.

The recoil detectors are likely to be silicon strip. From these we will get energy, position, and time. Detected energies, including consideration of the silicon detector dead layer, will range from 0.5 to 5.2 MeV for $0.0015<-t<0.010$ $(\mathrm{GeV/c})^2$. These will be closely related to $-t$. For detectors about 30 cm from the target (see slide 5), values of the time-of-flight values ranges between 8 and 29 ns. This is well away from the 55-ns time for the beam to go to the intersection region and return to a point 8.2 m away (the separation between pulses from the two beams passing through the jet target).

The holding field generates left/right asymmetries in the position of tracks on the face of the detectors, as shown in slide 6. For either polarity of the holding field, detectors 6.4 cm across will capture all the relevant protons for a measurement with the limits above on $-t$. The calibration requires clean identification of the elastic recoil protons. To be safe, other processes should be less than a percent of the signal; some UA6 data shown on slide 7 suggests that it may be as high as 2-3%. Additional detectors for the forward proton could help by providing an additional coincidence and coplanarity information. It is not known how close such "Roman Pot" detectors can be placed to the beam, but problems here might mean operating at larger values of $-t$ where both the cross sections and the analyzing powers are smaller.

RHIC Polarization Calibration Experiment

General Comments

Calibration reference standard:

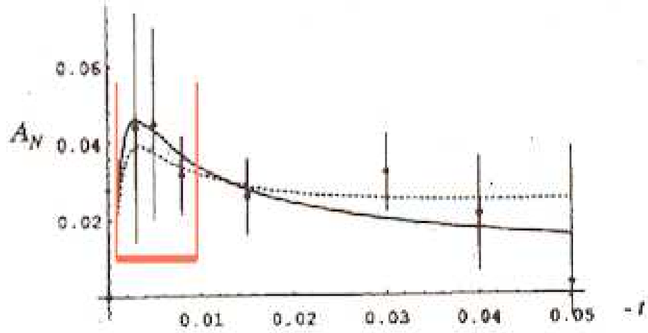
atomic beam polarized proton target

measure p with Breit-Rabi polarimeter (known to <3%)

Process: p+p elastic scattering in the CNI region

calculated A is above 0.033

for $0.0015 < -t < 0.01$ $(GeV/c)^2$



N.H. Buttimore *et al.*, PRD **59**, 114010

Features:

- same analyzing power A for beam or target in same geometry
  (any reaction would have to match two acceptances)
- CNI has A that is present independent of energy
- CNI has large cross sections
  rapid measurements
  large signal/noise ratio (other processes)
- hopefully simple, inexpensive experimental setup

Issues:

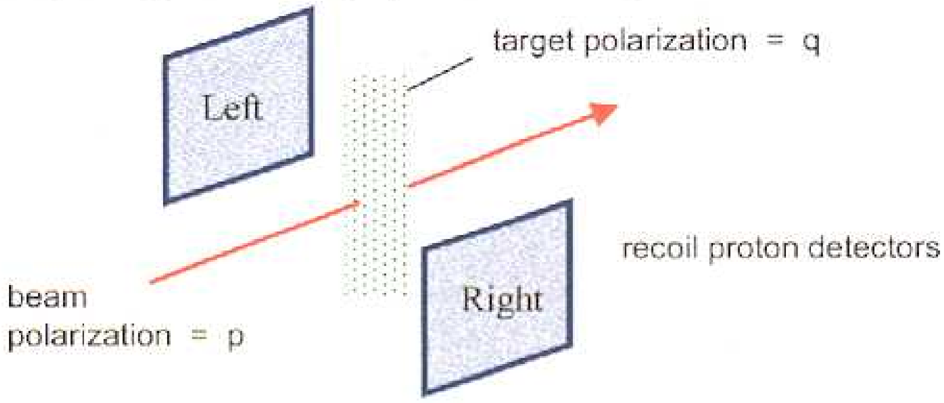
- low analyzing power makes systematic errors important

Goal:

calibration of blue/yellow ring p+C CNI polarimeters to <5%

reference standard for p+C CNI systematic studies

Simple geometry (for recoils)



Example: measure on both sides and flip either spin = 8 rates
Consider vertical spin only.

Calibration is a measure of this ratio

$$8\sigma \begin{bmatrix} 1 \\ pA \\ qA \\ pqA_{NN} \\ G \\ H \\ J \\ K \end{bmatrix} = \begin{bmatrix} +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 \\ +1 & -1 & -1 & +1 & +1 & -1 & -1 & +1 \\ +1 & -1 & +1 & -1 & -1 & +1 & -1 & +1 \\ +1 & +1 & -1 & -1 & -1 & -1 & +1 & +1 \\ +1 & +1 & +1 & +1 & -1 & -1 & -1 & -1 \\ +1 & -1 & -1 & +1 & -1 & +1 & +1 & -1 \\ +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 & +1 & +1 & -1 & -1 \end{bmatrix} \begin{bmatrix} L_{++} \\ R_{++} \\ L_{-+} \\ R_{-+} \\ L_{+-} \\ R_{+-} \\ L_{--} \\ R_{--} \end{bmatrix}$$

G = H = J = K = 0 unless there is a "reversal failure." Such failures are absent in their leading order from the first 4 terms.

incomplete beam flip

$$p_+ = \delta + p$$
$$p_- = \delta - p$$

$$J = \delta A$$
$$G = \delta q\, A_{NN}$$

incomplete target flip

$$q_+ = \varepsilon + q$$
$$q_- = \varepsilon - q$$

$$J = \varepsilon A$$
$$K = \varepsilon p\, A_{NN}$$

left/right imbalance

$$L \leftarrow L(1+\phi)$$
$$R \leftarrow R(1-\phi)$$

$$J = \phi$$
$$K = \phi p\, A$$
$$G = \phi q\, A$$
$$H = \phi pq\, A_{NN}$$

Count Rate Estimates

Proton beam: 10^{11} /bunch, 55 bunches

Target: 3×10^{11} /cm^2

luminosity = 1.3×10^{29} /cm^2/s

Cross section: 29 μb into one detector
for $0.0015 < -t < 0.01$ (GeV/c)^2
[calculated using $\rho = -0.09$, b = 11 (GeV/c)$^{-2}$

Rate = 15 /s (for 4 detectors, all bunches)

What is needed?

Analyzing power: 0.035

Beam polarization (target will be larger): 0.5

Asymmetry: 0.018

A 5% error requires $\delta\varepsilon = 0.00088$

Statistical precision requires more than 1.3×10^6 events

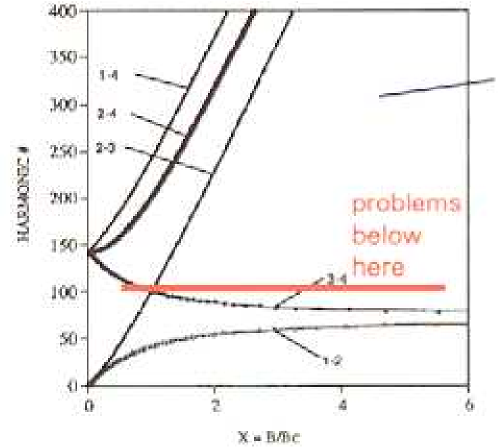
Run time = 24 hours (average over all bunches)

Effect on beam lifetime negligable from nuclear reactions.

Target Properties:

Atomic beam will be about 1.2 cm across. This spreads the origin point for events as seen by the recoil detectors.

It will be important to avoid resonant depolarization from RF in the beam. There is significant power at harmonics up through 100.



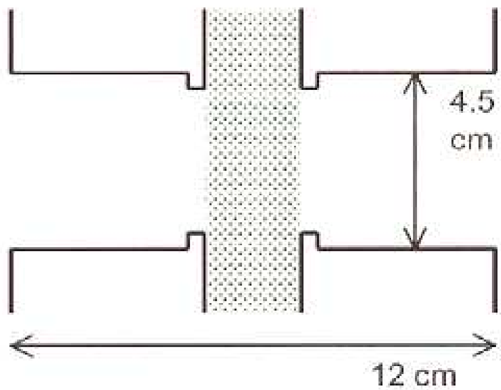
Use a holding field to retain polarization.

Plot shows resonances (dots) to be avoided as a function of harmonic number and holding field strength.

Magnetic field has to be high enough so that the space between resonances will allow for field non-uniformities.

B ~ 1.1 kG

There will be a holding field magnet something like:



NOTE: There needs to be a way to test (RF cavity?) to know whether field is off resonance.

This create left/right differences in the recoil proton trajectories! So plan to reverse field to cancel systematic errors.

Detectors likely to be silicon strip (cooled).
Pitch along beam path can be 2-3 mm.

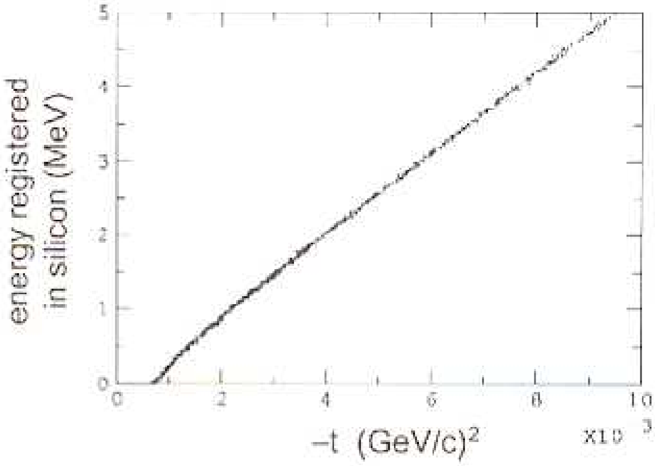
Grid will be needed between target and detector to shield and contain beam RF.

Detector/target chamber must be differentially pumped. Proton energies are too low for a separator foil.

What information is available from recoil measurement?

(1) energy

Within $0.0015 < -t < 0.01$ $(GeV/c)^2$, energy seen in silicon detector ranges from 0.5 to 5.2 MeV.

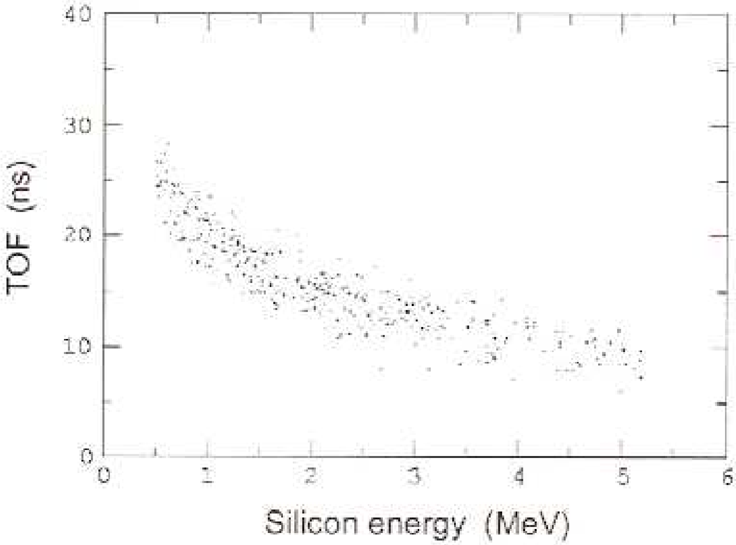


(2) position

2-3 mm resolution along beam direction is adequate.

(3) time of flight (relative to RF?)

Correlation of TOF with energy (0.5 – 5.2 MeV range):



Tracking proton trajectories to each detector:

Toy simulation

- Use information on IUCF double-sided silicon strip detectors from thesis of Todd Peterson. Detectors are 6.4×6.4 cm^2.
- Include silicon detector dead layer
- Include 55-keV noise, 1.6-ns time jitter
- Sharp-edged B-field
- Randomize source spot
- Place detectors at 30-cm distance

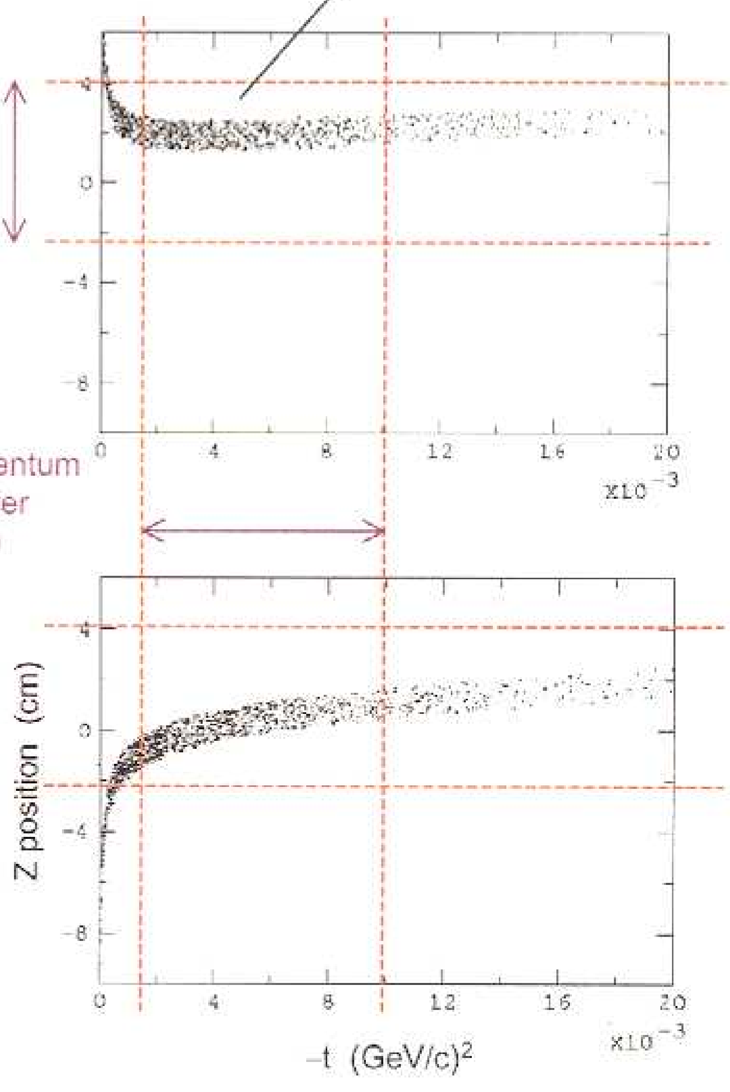
That turning point comes near CNI region is coincidental.

detector size

With detectors 6.4 cm wide at 30 cm, CNI recoil protons hit for both field directions.

momentum transfer range

With target 8.2 m from BRAHMS I.P., blue and yellow beams are separated by 55 ns, almost exactly half of pulse separation period. For TOF to fall in the middle, detectors must be closer than 50 cm.



Background: at what level does it matter?

Assume background is a fraction δ of the signal.

Then we measure

$$A_{\mathrm{exp}} = A - \delta(A' - A)$$

p+p elastic analyzing power

background analyzing power

Assume $\langle A \rangle$ = 0.035 near CNI peak.
Systematic errors should be < 5%, or < 0.0018.

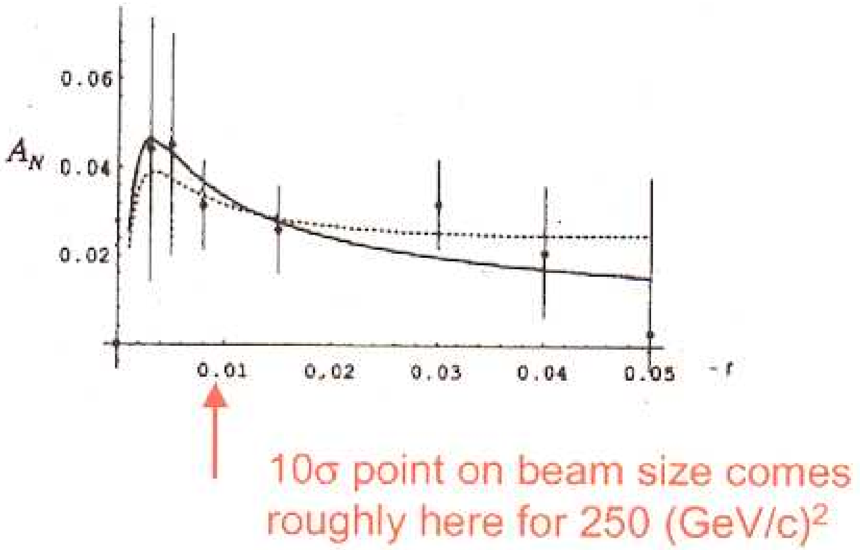
If A is:	then δ is:
1 (safe)	< 0.002
0.3	< 0.006

Can pp2pp Roman pots help?

require coincidence with forward proton

segmentation of Roman pot silicon and vertical direction on proton recoils makes possible a coplanarity cut

* minimum separation of forward detectors from beam may change CNI acceptance range



Limits imposed by non-Gaussian halo not known, may be strong function of location, time into store, other targets...

Moving out in momentum transfer reduces δ.

Background simulations needed to determine whether coincidences and cuts can meet δ goal.